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Techniques for Reducing Slope Stability Problems, Erosion and Sedimentation Due to Road Construction - An Annotated Bibliography

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TECHNIQUES FOR REDUCING SLOPE STABILITY PROBLEMS, EROSION AND SEDIMENTATION DUE TO ROAD CONSTRUCTION - AN ANNOTATED BIBLIOGRAPHY

This is an annotated bibliography to assist field personnel in reviewing sources of information on methodology for reducing slope stability problems associated with road construction. Reduction of erosion and sedimentation from roads is also covered since they are so closely associated with slope stability. Not all available literature is incorporated in this paper. Emphasis has been placed on references that would be most useful to field personnel in solving slope stability, erosion and sedimentation problems in Idaho. Much of the research and studies have been done in the Pacific Northwest, so many of the sources included herein originated from that region. In most cases the annotation consists of the author's abstract or excerpted passages from it. Otherwise, a brief summary of the literature reference has been provided.

Amaranthus, M.P., R.M. Rice, N.R. Barr and R.R. Ziemer. 1985. Logging and forest roads related to increased debris slides in southwestern Oregon. J. Forestry 83(4): 229-233.

Debris slides over a 20-year period were inventoried on 137,500 acres of forested land in the Klamath Mountains of southwest Oregon. Erosion rates on roads and landings were 100 times those on undisturbed areas, while erosion on harvested areas was seven times that of undisturbed areas. Three quarters of the slides were found on slopes steeper than 70 percent and half were on the lower third of slopes. The study area was subdivided into nine geomorphological erosion response units which exhibited profound differences in natural erosion rates and responses to disturbance. The results serve as a guide to appraising slide risk associated with timber harvests or road construction on forested slopes. (Excerpted from author's abstract)

Bell, J.R. and Q.R. Keener. 1973. An investigation of the feasibility of a cutbank slope design based on the analysis of natural slopes. pp. 131-155 In Proceedings of 11th Annual Symposium of Engineering Geology and Soils Engineering. Pocatello, Idaho. Report to USDA Forest Service.

The failure of cutbanks is a major problem encountered by those who construct low-cost roads in naturally forested residual soils. Although attempts are made to design roadways with low first cost, and hopefully low later maintenance costs, seldom are both of these goals realized. This results from the fact that at present there are no rational or semi-rational design methods used, and design is based on empirical means. Nothing relative to the physical geometry of the existing slope and the cutslope that influences slide behavior has been attempted.

The purpose of this investigation was to determine if a better cutbank design technique might be evolved from an analysis of natural slopes, cuts made into those slope, and failures that occurred because of cutting.

Field data was collected on 79 slides along forest access roads cut in residual volcanic soils of the Umpqua National Forest located in the Western Cascades of Oregon. This data was then compared with a theory developed for failures in cuts made into natural slopes of such residual soils. The theory was substantiated by the field data and was used to develop design curves which could, in turn, be used to predict the percentage that failures may be reduced from those occurring at present.

Beschta, R.L. 1978. Long-term patterns of sediment production following road construction and logging in the Oregon Coast Range. Water Resources Research: 14(6):1011-1016.

Suspended sediment production after road construction, logging and slash disposal was significantly increased (P = 0.95s) on two watersheds in Oregon's Coast Range. A 25% patch-cut watershed showed increases during three of eight post-treatment years. These increases were caused primarily by mass soil erosion from roads. Monthly sediment concentrations before the occurrence of the annual peak flow were increased more than those following the annual peak. Surface erosion from a severe slash burn was the primary cause of increased sediment yields for five post-treatment years on a watershed that was 82% clearcut. Monthly sediment concentrations were generally increased throughout the winter runoff period on the watershed. The flushing of suspended sediment in Oregon Coast Range watersheds is apparent from seasonal changes of suspended sediment rating curves. (Author's abstract)

Bethlahmy, N. and W.J. Kidd. 1966. Controlling soil movement from steep road fills. USDA For. Serv. Res. Note INT-45. USDA Forest Service, Intermountain Forest & Range Experiment Station, Ogden, Utah. 4 p.

Eight test plots were established on the fill slope of a newly constructed road. One plot was retained as a control, while different soil-stabilizing treatments were used on each of the other plots. These consisted of various combinations of seeding, fertilizing, mulching, and surface netting. Treatments that included both straw mulch and netting effectively controlled erosion. (Author's abstract)

Burroughs, Edward R., Jr. 1985. Survey of slope stability problems on forest lands in the west. pp. 5-15. In Proceedings of a Workshop on Slope Stability: Problems and Solutions in Forest Management. Feb. 6-8, 1984. Seattle, Wash.

Within the region west of central Montana and north of San Francisco, the intersection of areas with high hazard levels for natural landslides, important fishery-water resources and major levels of management activity represent areas with a large potential for environmental damage as a result of timber harvest. The percentage of land in the Northern, Intermountain, Pacific Northwest and Pacific Southwest Regions with a high potential for mass failures ranges from 10 to 12 percent. Road construction costs per mile increase by a factor of about four from south Idaho to Washington and Oregon. Annual road maintenance costs can increase by a factor of 13 in areas with a high potential for road cut failures. Intensive slope stability surveys can be used to identify timber harvest sites within a larger area generally classified as unstable. (Excerpted from author's abstract)

Burroughs, Edward R., Jr., G.R. Chalfant, and M.A. Townsend. 1976. Slope stability in road construction - a guide to the construction of stable roads in western Oregon and northern California. USDI Bureau of Land Management. Portland, Oregon. 102 p.

This booklet discusses the basic principles of slope stability and their utilization to construct stable roads. A general outline of the geology of Western Oregon and northern California is presented as a basis for discussing specific slope stability problems. Techniques for construction of stable roads in each of the geologic types are reviewed along with maintenance needs.

Burroughs, Edward R., Jr. and John G. King. 1989. Reduction of soil erosion on forest roads. Gen. Tech. Report INT-264. USDA, Forest Service, Intermountain Research Station, Ogden, Utah.

Results of on-site erosion control work from across the United States provide estimates of the amount of erosion reduction on forest roads from various treatments. Supplementary information includes the effects of slope gradient, soil characteristics, and ground cover. Estimates of sediment travel below fillslopes can be made, together with the combined effect of erosion control treatments of the running surface, road cut, and ditch. (Author's abstract)

Burroughs, Edward R., Jr., F.J. Watts, and D.F. Haber. 1984. Surfacing to reduce erosion of forest roads built in granitic soils. pp. 255-264. In Proceedings of Symposium on Effects of Forest Land Use on Erosion and Slope Stability. May 7-11, 1984. Honolulu, Hawaii.

A sprinkling infiltrometer was used to measure the relative difference in sediment yield from 15.3 to 30.5 m isolated lengths of forest road. Sediment yield was reduced by a factor of 4.3 for gravel surfacing, 3.2 for dust oil and 28.7 for bituminous surfacing relative to an unsurfaced road. Gravel spread in the ditch reduced sediment yield by a factor of 2.3 relative to an unprotected ditch. A rutted unsurfaced road produced twice the sediment of a smooth unsurfaced road. (Author's abstract)

Clayton, James L. 1983. Evaluating slope stability prior to road construction. USDA Forest Service Research Paper INT-307. Intermountain Forest & Range Experiment Station, Ogden, Utah. 6 p.

Subsurface bedrock properties play an important role in determining slope stability in the Idaho batholith; however, properties like degree of weathering are difficult to define prior to construction. The usefulness of seismic, resistivity, and vegetation surveys for predicting subsurface strength characteristics of granitic rock was evaluated in the Idaho batholith. Eleven of twelve zones identified as highly weathered following construction were predicted by one or more surveys along a proposed road centerline. Using the same criteria, 10 other zones would have been predicted to contain highly weathered rock, but did not. Preconstruction geophysical and vegetation surveys may efficiently narrow the number of sites requiring additional surface exploration or drilling for drainage location, or locate sites requiring physical structures for road stabilization. (Excerpted from author's abstract)

Cook, Michael J. and John G. King. 1983. Construction cost and erosion effectiveness of filter windrows on fill slopes. USDA Forest Service Research Note INT-335. Intermountain Forest & Range Experiment Station, Ogden, Utah. 5 p.

Sediment barriers of slash were designed and constructed on the fill slopes of newly constructed roads. These barriers called filter windrows were located in the vicinity of stream crossings in an attempt to prevent eroded fill material from entering the stream. A conservative estimate of the sediment trapping efficiency of the windrows is 75 to 85 percent, based on measurements of fill slope erosion on windrowed versus non windrowed slopes. The results indicate that the construction of filter windrows on fill slopes is a relatively inexpensive and a very effective treatment for preventing eroded material from entering adjacent streams. Filter windrows can be constructed simultaneously with road construction, providing immediate protection of the water resources. (Excerpted from author's abstract)

Darrach, A.G., N.M. Curtis, and W.J. Sauerwein. 1978. Estimating sheet-rill erosion and sediment yield on rural and forest highways. USDA Soil Conservation Service Technical Note. Woodland-No. 12. 41 p.

This technical guide outlines a procedure to evaluate sheet and rill erosion on rural and forest roadways. This method utilizes the Universal Soil Loss Equation (USLE) and is of value to land managers, planners and resource specialists for impact assessment and design of low volume roads.

Duncan, S.H. 1985. Road location in sensitive watersheds: an industry perspective. pp. 78-80 In Proceedings of a Workshop on Slope Stability: Problems and Solutions in Forest Management. Feb. 6-88, 1984. Seattle, Wash.

The identification of potentially unstable areas for road location and harvest planning in sensitive watersheds can be done at three levels of resolution. The broadest level involves the use of soil survey or geologic maps and is useful in general identification of particularly sensitive areas. Once the sensitive areas are identified, the second level of resolution recognizes individual landscape units and notes particular slope stability characteristics as the basis for general management recommendations. The third level must be accomplished on site at the time of road and landing location. At this point, fairly specific construction recommendations can be outlined. (Author's abstract)

Duncan, S.H., J.W. Ward and R.J. Anderson. 1987. A method for assessing landslide potential as an aid in forest road placement. Northwest Science 61(3): 152-159.

Specific landscape parameters associated with landslides from forest roads were examined in the coast and Cascade ranges of western Washington and western Oregon to develop a slope stability risk

assessment technique that can be used by logging engineers as an aid in road location, design and construction in areas of questionable slope stability. Using stepwise discriminant function analysis, the sum of scores representing nine individual slope stability variables resulted in a classification between fail and no-fail sites at 88 and 66 percent accuracy, respectively, at the 0.01 level of confidence. By adjustment of individual weighing values, the qualitative technique presented here can be adapted to other areas to assess landslide risk. (Excerpted from author's abstract)

Dyrness, C.T. 1970. Stabilization of newly constructed road backslopes by mulch and grass-legume treatments. USDA Forest Service Research Note PNW - 123. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon. 5 p.

Amounts of soil loss from an unprotected newly constructed backslope were two to four times greater than loss from a comparable slope five years after construction. Of six roadside treatments studied, the two showing consistently large amounts of soil loss during the first critical rainy period were the only ones without a straw mulch covering. (Author's abstract)

Eckel, Edwin B. 1958. Landslides and engineering practice. Highway Res. Board Spec. Rep 29. NAS-NRC Publ. 544. Wash, D.C. 232 p.

This text is intended for use in recognizing, avoiding, controlling, designing for, or correcting the more important types of landslide movements. The book is divided into two parts. Part I is intended to provide the engineer with the tools and methods he needs to solve an actual or potential landslide problem. Part II summarizes the methods known to have been applied to the prevention and control of landslides. It also discusses the methods of making stability analyses and of using them in the solution of design problems.

Fredriksen, R.L. 1963. A case history of a mud and rock slide on an experimental watershed. USDA Forest Service Research Note PNW-1. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon. 4 p.

On December 19, 1961, almost 3,000 feet of creek bed on the H. J. Andrews Experimental Forest near Blue River, Oregon, was scoured to bedrock by a landslide. This paper examines the events leading up to the slide, the mechanism of the slide and the causal agents that helped trigger it.

Fredriksen, R.L. 1970. Erosion and sedimentation following road construction and timber harvest on unstable soils in three small western Oregon watersheds. USDA Forest Service Research Paper PNW -104, Pacific Northwest Forest & Range Experiment Station, Portland, Oregon. 15 p.

In two steep headwater drainages, landslides were the predominant source of increased sedimentation of streams following timber harvest. Patch-cut logging with forest roads increased sedimentation compared with a control by more than 100 times over a 9-year period. Landslide erosion was greatest where roads crossed high gradient stream channels. In an adjacent clearcut watershed with no roads, sedimentation increased three times that of the control. (Author's abstract)

Froehlich, Henry A. 1978. The influence of clearcutting and road building activities on landscape stability in western United States. pp. 165-173 In Proceedings of the 5th. North American Forest Soils Conference. Colorado State Univ., Fort Collins.

This paper reviews published literature on mass soil movement. Timber harvesting and road building impacts are the primary focus. A comparison is made of the rate of soil movement in managed areas with mass soil movement in undisturbed areas.

Gardner, R.B., W.S. Hartsog and K.B. Dye. 1978. Road design guidelines for the Idaho Batholith based on the China Glenn road study. USDA Forest Service Research Paper INT-204. Intermountain Forest & Range Experiment Station, Ogden, Utah. 20 p.

Erosion caused by road construction on the steep, fragile, decomposed granitic soils of the Idaho Batholith resulted in a 1965 moratorium on road construction in the South Fork of the Salmon River and its tributaries. In 1970, The China Glenn Road was built to salvage trees attacked by the Douglas-fir beetle and protect the residual stand. It was constructed well back of the river-break zone on slopes averaging 40-50 percent. A key objective was to build a road with as little environmental impact as possible. A single-lane (12 foot (3.66 m)) road following the contour without a ditch, and with special design features, has proved adequate for logging, with little adverse impact. (Author's abstract)

Gonsior, M.J. and R.B. Gardner. 1971. Investigation of slope failures in the Idaho Batholiths. USDA Forest Service Research Paper INT-97. Intermountain Forest & Range Experiment Station, Ogden, Utah. 34 p.

Precipitation events in the winter and spring of 1965 caused significant erosion and numerous landslides in many parts of the Idaho Batholith. Most slope failures were associated with roads. An investigation of several representative failures in the Zena Creek sale area on the Payette National Forest was conducted. Details of the field and laboratory tests are given, and three examples of the stability analyses are presented. Causes of the failures are discussed and recommendations for future construction in similar terrain are made. (Author's abstract)

Haupt, H.F. 1959. A method for controlling sediment from logging roads. USDA Forest Service Misc. Pub. 22. Intermountain Forest & Range Experiment Station,Ogden, Utah. 22 p.

This publication describes a method of controlling sediment from logging roads on cutover ponderosa pine lands of southwestern Idaho. A multiple regression equation was developed relating sediment flow distance in feet to four significant road and downslope characteristics: slope obstruction index, cross ditch interval squared, embankment slope length and cross ditch interval times road gradient.

The control method is applied using favorable road location, liberal cross ditching and reduction of the slope obstruction index by placement of logging debris.

Haupt, H.F., H.C. Rickard and L.E. Finn. 1963. Effect of severe rainstorms on insloped and outsloped roads. USDA Forest Service Research Paper INT-1. Intermountain Forest & Range Experiment Station, Ogden, Utah. 8 p.

Three heavy rainstorms that produced from about 7.5 to 10.0 inches of rain in central Idaho in a 10-day period in October 1962, caused considerable damage to newly constructed logging roads. Insloping a roadbed under the time, topographic, soil and storm conditions described is more desirable than outsloping as a measure for preventing erosion and damage to the roads. (Author's abstract)

Hungerford, Roger D. 1984. Native shrubs: suitability for revegetating road cuts in northwestern Montana. USDA Forest Service Research Paper INT-331. Intermountain Forest & Range Experiment Station, Ogden, Utah. 13 p.

Most road cuts and fill slopes on National Forests are seeded with grasses and legumes to aid revegetation. Fill slopes respond well to this treatment, but harsh sites and cut banks usually remain barren. The purpose of this study was to evaluate the use of shrubs and forbs native to northern idaho and western montana for revegetation along western Montana road cuts.

Kidd, W.J., Jr. and H.F. Haupt. 1968. Effects of seedbed treatment on grass establishment on logging roadbeds in central Idaho. USDA Forest Service Research Paper INT-53. Intermountain Forest & Range Experiment Station, Ogden, Utah. 9 p.

Deep and shallow scarification treatments, before and after broadcasting seed, were studied to determine if they would be conducive to establishment of a heavier stand of grass than could be obtained by merely broadcasting seed. Mulching with wood chips and fertilizing were also tried. Results show a slight advantage for deep scarification before seeding. Three of five perennial species became well established; the other two did poorly. (Excerpted from author's abstract)

Kidd, W.J., Jr. and J.N. Kochenderfer. 1973. Soil constraints on logging road construction on steep land east and west. J. Forestry 71(5): 280-283.

This paper presents a summary of major problems encountered by road and trail builders in steep forest land. Common road building problems and solutions are briefly discussed.

Kochenderfer, James N. 1970. Erosion control on logging roads - the Appalachians. USDA Forest Service Research Paper NE-158. 28 p.

Practical methods of controlling erosion on logging roads are summarized through the different stages--planning, location, drainage, maintenance, and care after logging. The material was derived from existing literature, road lore, contact with experienced land managers, and personal experience. (Author's abstract)

Krag, R. K. 1980. A method to estimate risk of soil erosion to logging sites in the Kootenai area of British Columbia. For. Eng. Research Inst. of Canada. Technical Report No. TR-38. 50 p.

The risk of surface erosion and slope failure to logging sites in the Kootenai area of British Columbia can be determined using these guidelines. Soil texture and particle size distribution, site moisture regime, slope and soil depth are used to develop a hazard rating system. Harvesting system and road standard, location and construction guidelines are given for each erosion hazard class. Methodology has potential for widespread usage in other areas with modification.

LaHusen, R.G. 1984. Characteristics of management-related debris flows, northwestern California. pp. 139-145. In Proceedings of Symposium on Effects of Forest Land Use on Erosion and Slope Stability. May 7-11, 1984. Honolulu, Hawaii.

An inventory of landslides in the lower Redwood Creek basin, California showed that erosion due to shallow landslides has been accelerated by logging-road and skid trail construction. The analysis of landslides occurring during the 1981-82 rainfall season showed that all debris flows originated from roads or skid trails on slopes with gradients of at least 30 degrees. Furthermore, 90 percent of the inventoried features originated less than 30 meters below a major convex break-in-slope and 87.5 percent of the failures occurred in a poorly drained soil having a mottled horizon less than one meter from the surface. Results of this study are being applied in an erosion control program to selectively identify road reaches with high failure potential. (Excerpted from author's abstract)

Larse, Robert W. 1971. Prevention and control of erosion and stream sedimentation from forest roads. pp. 76-83. In Proceedings of Symposium on Forest Land Use and Stream Environments. Oregon State University, Corvallis. Oct. 19-21, 1970.

To minimize erosion and resultant stream sedimentation, prevention and control measures must be given consideration in every aspect of road planning, design, construction and maintenance. In mountainous terrain the forest land manager must establish specific objectives and prescriptions to guide road network construction and utilize the combined professional skills of the forester, engineer, geologist, biologist, and others to set standards for the protection of watershed values, identify alternatives, and offer solutions to specific problems.

The decision to road an area should only be made after the resource-serving benefits have been carefully weighed against the cost and effect of roading on the watershed. The decision not-to-road and to accept other alternatives for land-use management must be strongly considered when the probability of lasting soil, water, and other ecological values is recognized. (Author's abstract)

McCashion, John D., and Raymond M. Rice. 1983. Erosion on logging roads in northwestern California. How much is avoidable? J. Forestry. 81(1): 23-26.

A study was made on 344 miles of logging roads in northwestern California to assess sources of erosion and the extent to which road-related erosion is avoidable. At most, about 24 percent of the erosion measured on the logging roads could have been prevented by conventional engineering methods. The remaining 76 percent was caused by site conditions and choice of alignment. On 30,300 acres of commercial timberland, an estimated 40 percent of the total erosion associated with management of the area was found to have been derived from the road system. (Author's abstract)

Megahan, Walter F. 1974. Deep rooted plants for erosion control on granitic road fills in the Idaho Batholith. USDA Forest Service Research Paper INT-161. Intermountain Forest & Range Experiment Station, Ogden, Utah. 18 p.

A study, designed with three replications of 10 treatments on 1/200-acre study plots, was conducted to evaluate how well ponderosa pine survives, grows, and reduces surface erosion on granitic road fills in the Idaho Batholith. Tree survival averaged about 97 percent after four growing seasons. Fertilizer increased planted tree growth an average of 95 percent during the year of peak effect. Tree planting, coupled with straw mulch and erosion netting, reduced erosion on an average of about 95 percent over three years. Planted trees alone provided 32 to 51 percent erosion reduction. Planting ponderosa pine at a spacing of 3 X 3 to 4 X 4 feet is recommended as an erosion-control measure for granitic road fills in the idaho Batholith. (Excerpted from author's abstract)

Megahan, Walter F. 1977. Reducing erosional impacts of roads. pp. 237-261. In Guidelines for watershed management, FAO Conservation Guide. Food and Agriculture Organization of the United Nations, Rome.

Guidelines for reducing erosional impacts of roads in Third World countries. Methods outlined are based on the principles of minimizing the miles of road and degree of disturbance, avoiding high erosion hazard areas, reducing erosion on the areas that are disturbed and minimizing the off-site impacts of erosion that occurs. General concepts presented have wide applicability.

Megahan, Walter F. 1978. Erosion processes on steep granitic road fills in central Idaho. Soil Science Society of America Journal. 42(2): 350-357.

A set of thirty 1/200 acre erosion plots was used to study erosion occurring on steep road fills constructed with granitic soil materials in the Idaho Batholith. Erosion on bare control plots averaged 3.4 metric tons/km^2 per day for water years 1970 through 1972. Erosion was reduced an average of 44% and 95% by tree planting and straw mulching, respectively. Daily erosion rates were consistently

higher during summer periods than during snow-free winter periods, presumably because of greater rainfall energy during the summer. Dry creep accounted for at least 15% of the total annual erosion for the years sampled and was as high as 40% in 1971. The median particle size of eroded materials tended to decrease throughout the summer and fall until mid-October when it abruptly increased. (Excerpted from author's abstract)

Megahan, Walter F. 1981. Effects of silvicultural practices on erosion and sedimentation in the interior West--a case for sediment budgeting. pp. 169-181. In Proceedings of Symposium on Interior West Watershed Management. Apr. 8-10, 1980. Spokane, Wash.

Accelerated surface and mass erosion are often caused by silvicultural practices in the interior western United States. On-site erosional impacts may also be manifested at downstream locations as increased sedimentation. Expressed per unit area of soil disturbing practice, roads are the primary cause of accelerated erosion and sedimentation. An understanding of erosional processes is important to efficiently reduce surface and mass erosion. Sediment budgeting is an important consideration for evaluating the amount and effects of erosion and the resulting downstream sedimentation. (Excerpted from author's abstract)

Megahan, Walter F. 1985. Road effects and impacts - watershed. pp. 57-97. In Proceedings Forest Transportation Symposium. Dec. 11-13, 1984. Casper, Wyoming.

This paper discusses the effects and impacts of road construction on watershed function and on-site productivity of timber producing lands. Principles of erosion control are outlined along with general examples of their application to road construction.

Megahan, Walter F. 1986. Recent studies on erosion and its control on forest lands in the United States. pp. 178-189. In Forest Environment and Silviculture: Proceedings of the 18TH IUFRO World Congress, Sept. 7-21, 1986, Ljubljana, Yugoslavia.

Research on erosion and erosion control conducted in the United States since the last World Forestry Congress is reviewed. Effects of road construction, forest fire, and timber harvest are considered in relation to surface and mass erosion. A discussion of methods for predicting surface erosion and defining mass erosion hazards is presented. (Excerpted from author's abstract)

Megahan, Walter F. 1987. Effects of forest roads on watershed function in mountainous areas. pp. 335-348. In Environmental Geotechnics and Problematic Soils and Rocks. Balasubramaniam et. al. (eds). Balkema, Rotterdam.

Numerous examples from mountainous areas in the interior Western United States are used to illustrate the effects of forest road construction on watershed functions. Impacts can occur at on-site and downstream locations. Accelerated surface and mass erosion and resulting sedimentation are the

most common and serious kinds of watershed damages caused by road construction. Basic principles for reducing road erosion and sedimentation impacts are presented. (Excerpted from author's abstract)

Megahan, W.F. and C.C. Bohn. 1989. Progressive, long-term slope failure following road construction and logging on noncohesive, granitic soils of the Idaho batholith. pp. 501-510. In Headwaters Hydrology, American Water Resources Assoc. June, 1989.

Piping failures caused by progressive, small-scale liquefaction of the cohesionless, granitic soil materials have not been well documented to date. Since 1984, we have been monitoring three such failures on three experimental watersheds in the Silver Creek Study Area. Annual erosion rates appear to be related to the annual peak runoff from the experimental watersheds which in turn serves as an index of groundwater conditions. Such failures are important because they are forest management related, continue over a long term, are not easily detected, and may supply eroded material directly to the drainage system. (Excerpted from author's abstract)

Megahan, W.F., N.F. Day and T.M. Bliss. 1978. Landslide occurrence in the western and central Northern Rocky Mountain physiographic province in Idaho. pp. 116-139. In Proceedings 5th North American Forest Soils Conference, Colorado State Univ., Fort Collins.

The Northern Rocky Mountain province comprises the mountainous headwaters of the Columbia and Missouri River drainages (Fenneman, 1931). The region includes most of Idaho and western Montana and a small portion of eastern Washington (Fig. 1). This area is not known for slope stability problems as are some other locations in the western United States, such as the Gros Ventre area (Bailey, 1974) and coastal ranges in northern California, Oregon, and Washington (Swanston, 1974). Even so, landslide hazards are high in the Northern Rocky Mountains because of steep slopes, shallow soils, and high ground water levels caused by large rainstorms and/or snowmelt. (Author's abstract)

Megahan, W.F. and W.J. Kidd. 1972. Effects of logging and logging roads on erosion and sediment deposition from steep terrain. J. Forestry 70(3): 136-141.

Erosion plots and sediment dams were used to evaluate the effects of jammer and skyline logging systems on erosion and sedimentation in seep, ephemeral drainages in the Idaho Batholith of central Idaho. Five-year plot data indicated that no difference in erosion resulted from the two skidding systems as applied in the study. Sediment dam data obtained concurrently showed that the logging operations alone (excluding roads) increased sediment production by a factor of about 0.6 over the natural sedimentation rate. Roads associated with the jammer logging system increased sediment production an average of about 750 times over the natural rate for the six-year period following construction. (Author's abstract)

Megahan, W.F. and W.J. Kidd. 1972. Effect of logging roads on sediment production rates in the Idaho batholith. USDA Forest Service Research Paper INT-123. Intermountain Forest & Range Experiment Station, Ogden, Utah. 14 p.

Effects of logging road construction on sediment production rates were studied on small, ephemeral drainages in the Idaho Batholith, a large area of granitic rock characterized by steep slopes and highly erodible soils. For the 6-year study period, about 30 percent of the total accelerated sediment production from roads was caused by surface erosion; the remainder resulted from mass erosion. Surface erosion on roads decreased rapidly with time after extremely high initial rates. A mass failure of a road fill slope occurred about 4 years after construction, when surface erosion had fallen to a low rate. The sediment production rate attributed to erosion within the area disturbed by road construction averaged 770 times greater (220 because of surface erosion and 550 because of mass erosion) than that for similar, undisturbed lands in the vicinity.

Results suggest three guides to use in the control of surface erosion on roads and subsequent downslope sediment movement in the Idaho Batholith: (a) Apply erosion control measures immediately after road construction for maximum effectiveness; (b) ensure that treatments protect the soil surface until vegetation becomes established; and (c) take advantage of downslope barriers (logs, branches, etc.) to effectively delay and reduce the downslope movement of sediment. (Author's abstract)

Megahan, W.F., K.A. Seyedbagheri and P.C. Dodson. 1983. Long-term erosion on granitic roadcuts based on exposed tree roots. Earth Surface Processes and Landforms. Vol. 8: 19-28.

Exposed roots were used to estimate soil and bedrock erosion on the cut slopes of a 45-year old road constructed in granitic soils of the Idaho Batholith. The original roadcut surface was defined by projecting a straight line from the toe of the cut past the end of the exposed root to the intersection of a straight line projected along the surface of the hillslope. A cross-sectioning technique was then used to determine erosion to the present roadcut surface. A total of 41 exposed root sites were used to estimate erosion n a 1350 m-long section of road. Average erosion was 1.0 and 1.1 cm/year for soil and bedrock respectively. Buttressing by tree roots caused lower erosion rates for soil as compared to bedrock. Both soil and bedrock erosion rates showed statistically significant correlations with the gradients of the original cut slope. The bedrock erosion data provide a reasonable estimate of the disintegration rate of exposed granitic bedrock exhibiting the weathering and fracturing properties common to this area. The road is located in a study watershed where long-term sediment yield data are available. Sediment data from adjacent study watersheds with no roads were compared to sediment data from the roaded watershed to estimate the long-term increase in sediment yield caused by the road. The increase amounts to about 2.4 m^3/year. This figure, compared to the average annual on-site road erosion, provides an erosion to sediment delivery ratio of less than 10 per cent. Based on study results, road construction and maintenance practices are suggested for helping reduce roadcut erosion. (Author's abstract)

Nagygyor, Sandor A. 1984. Construction of environmentally sound forest roads in the Pacific Northwest. pp. 143-147. In Proceedings Conference COFE/IUFO. Aug 12-14, Orono, Maine.

The "trench" method, in combination with end-hauling to a safe disposal site is an accepted forest road construction technique. The method incorporates the old proven techniques with new ones that minimize soil erosion caused by road construction in the forest. (Author's abstract)

Noble, E.L. and F.J. Lundeen. 1971. Analysis of rehabilitation treatment alternatives for sediment control. pp. 86-96. In Proceedings Symposium Forest Land Use and Stream Environments, Oregon State University, Corvallis. Oct. 19-21, 1970.

The aquatic environment of the South Fork Salmon River has been severely damaged in recent years by excessive rates of sediment production. A special study was conducted to determine the source and extent of the damage, and measures required to reduce future sediment production to a "tolerable" level. Linear programming was used as an aid to select from 190 possible treatment alternatives and minimize treatment costs at various levels of sediment reduction. The desired level of sediment could be reached at a cost of $5 million. Debris basins to trap sediment moving in the channel proved to be the most effective and economical type of treatment while control of sediment production from roads and timber harvest on steep, fragile lands would have a very high cost. (author's abstract)

Packer, Paul E. 1967. Criteria for designing and locating roads to control sediment. For. Sci. 13(1): 1-18.

A recently completed study developed criteria for the design, location, and construction of logging roads in the northern Rocky Mountains to prevent damage to the water resource and to conserve soil. Results reveal which characteristics of watersheds and of secondary logging roads influence erosion of road surfaces and movement of sediment downslope from roads. They define the manner and degree in which these characteristics affect road-surface erosion and sediment movement, and they indicate which characteristics are controllable or alterable by design, management, or choice. They also provide the quantitative criteria needed to develop road design and location requirements that should be considered in planning and executing timber harvest operations, so that soil and water resources will be protected. (Author's abstract)

Packer, Paul E., and George F. Christensen. 1964. Guides for controlling sediment from secondary logging roads. USDA Forest Service Intermountain Forest & Range Experiment Station, Ogden, Utah and North Reg., Missoula, Mont. 42 p.

Numerous practical measures, including the use of berms, surfacing, surface drainage structures, and outsloping, have been employed to reduce erosion on roads and prevent sediment from reaching streams. Despite use of such preventive measures, erosion of road surfaces and fill slopes and movement of sediment from roads into streams continue on many of our timber sale areas. These conditions indicate that we do not yet fully understand what kinds of roads to build nor where to locate them in watersheds in order to prevent sedimentation.

Prospects for increased timber harvesting and other uses of forest land emphasize the need to understand how to locate and build the roads needed to serve these uses without causing undue damage to soil and water resources.

The guides in this handbook are largely the result of research in the Northern Region and also are partly the result of experience. They provide the reader with a basis for understanding how and where roads may be built safely under varying conditions of soil, topography, and vegetative cover. (Excerpted from author's preface)

Pole, Michael W. and Donald R. Satterlund, 1978. Plant indicators of slope instability. Journal of Soil and Water Conservation 78(5): 230-232.

Mass movement on disturbed, unstable slopes not only reduces productivity but is a major source of sediment in wildland areas. Prevention requires that disturbance be avoided on sites with high potential for mass movement, which, in turn, requires that such areas be readily identifiable. Understory plant indicators proved useful in identifying 60 percent of the sites showing evidence of deep-seated mass movement, such as rotational slumps and earth-flows, in Idaho's Clearwater National Forest. The ecological characteristics of plants that proved to be the most useful indicators suggest that ecologically analogous species might be used to identify many similar sites in other regions. (Author's abstract)

Potyondy, John P. 1981. Technical guide for erosion prevention and control on timber sale areas. USDA Forest Service Intermountain Region. 151 p.

This technical guide includes a summary of the timber sale contract provisions useful in planning and implementing erosion control on timber sales, a discussion of transportation system definitions and road standards as they relate to timber sales, a brief overview of forest practices and their erosional impacts and a discussion of erosion processes, concepts and specific control measures and practices useful for erosion control.

Prellwitz, Rodney W. 1975. Simplified slope design for low standard roads in mountainous areas. pp. 65-74. In Transp. Res. Board Spec. Rep. 160, Low Volume Roads.

Several simplified methods of analyzing the stability of soil slopes are discussed. The methods are restricted to uncomplicated forms suitable for field applications by designers with only limited soil mechanics background. All methods are based on long-term stability.

The following methods are included:

1. Infinite Slope Equations - For analyzing the stability of natural slopes with or without seepage parallel to the surface slope. Equations from Taylor (1) and Lambe and Whitman (2) are used as the basis.

2. Stability Number Chart - For analyzing the stability of a cut slope superimposed on a natural slope without seepage conditions. A chart constructed after data from Chen and Giger (3) is used.

3. Stability Number Chart (Seepage) - For analyzing the stability of a cut slope superimposed on a natural slope which has seepage conditions. No suitable simplified method of analysis is presently available. A suggested simplified form is proposed for development.

4. Simplified Stability Analysis of a Specific Failure Surface - A method is introduced which utilizes only the conditions at the center of gravity of the soil mass above the failure surface and the infinite slope equations previously presented. The procedure, sample applications, and comparisons to the Ordinary Method of Slices and Simplified Bishop's Method are given. (Author's abstract)

Prellwitz, R.W., T.R. Howard, and W.D. Wilson. 1982. Landslide analysis concepts for management of forest lands in residual and colluvial soils. In TRB Transportation Research Record 919. pp. 27-36.

A forest land management analysis scheme is discussed for dealing with landslides that occur in residual and colluvial soils. No one geotechnical or statistical model can be expected to apply to all levels of land management where an assessment of the potential for landslide is vital to a rational decision-making process. The U.S. Department of Agriculture Forest Service in cooperation with the University of Idaho is developing a scheme for evaluating soil-mantle landslide potential to provide information at three levels of land management activities: (a) resource planning; i.e., relative landslide hazard evaluation for resource allocation; (b) project planning; i.e., evaluation of management impacts for comparing alternate transportation routes and timber harvest techniques; and (c) road design and land stabilization; i.e., evaluation of alternate road stabilization techniques at a specific critical site. Both geotechnical and statistical analysis techniques are advocated so that the information can be in geotechnical form (factor of safety against failure or critical height of slope) or in statistical form (probability of landslide occurrence) with landslide inventories used as a link between the two. A hypothetical example of the three-level analysis is given. (Author's abstract)

Rice, Raymond M. 1977. Forest management to minimize landslide risk. pp. 271-287. In Guidelines for watershed management, FAO Conservation Guide. Food and Agriculture Organization of the UN, Rome.

Landslide types, factors related to occurrence of landslides and methodology used in appraisal of landslide risks is discussed in this paper. The effect of timber harvest, road building, fire and other management actions on slope stability are briefly presented along with resource damage that results from landslide events.

Rice, R.M., and S. Lewis. 1986. Identifying unstable sites on logging roads. pp. 239-247. In Proceedings of International Union of Forestry Research Organizations 18th World Congress. Ljubljana, Slovania.

The implications of forest management activities upon slope stability are discussed in this article. Landslide risk factors are portrayed and the mechanism of slope stability. The effect of road building, tree removal, fire and vegetation type conversions on landslides are enumerated in general terms.

Rice, R.M., J.S. Rothacher and W.F. Megahan. 1972. Erosional consequences of timber harvesting: an appraisal. pp. 321-329. In Proc. National Symp. on Watersheds in Transition. Fort Collins, Colorado. 1972.

This paper summarizes our current understanding of the effects of timber harvesting on erosion. Rates of erosion on mountain watersheds vary widely but the relative importance of different types of erosion and the consequences of disturbances remain fairly consistent. Therefore these conclusions seem to be valid for most circumstances: Most of man's activities will increase erosion to some extent in forested watersheds; erosion rarely occurs uniformly; sediment production declines rapidly following disturbance; landslides and creep are the chief forms of natural erosion in mountainous regions; cutting of trees does not significantly increase erosion, but clearcutting on steep unstable slopes may lead to increased mass erosion; accelerated erosion is a possible undesirable side effect of use of fire in conjunction with logging; the road system built for timber harvesting far overshadows logging or fire as a cause of increased erosion; and potentially hazardous areas can be identified in advance of the timber harvest. (Author's abstract)

Rothwell, R.L. 1978. Watershed management guidelines for logging and road construction in Alberta. Information Report NOR-X-208. Northern Forest Research Center. Canadian Forest Service. Edmonton, Alberta, Canada. 43 p.

Guidelines developed for logging operations and road construction in Alberta, Canada. The basic premise of these guidelines is that severe erosion and sedimentation can be prevented by minimizing soil disturbance and controlling surface runoff. The first section of this report briefly discusses erosion and watershed damage. The second and third sections present watershed management guidelines for logging, road construction and road maintenance.

Sander, E.A. 1984. Utilizing alternative logging methods to reduce mass wasting. pp. 223-230. In Proceedings of Symposium on Effects of Forest Land Use on Erosion and Slope Stability. May 7-11, 1984. Honolulu, Hawaii.

Three studies examined ways to reduce mass wasting by using alternative logging methods. Examination of slope failures in logged areas showed that: failure-prone sites could be identified; road failures were primarily caused by overloading steep slopes and by poor road-drainage practices; and yarding disturbance appeared to contribute to several failures within clearcuts. Examination of current

yarding operations showed levels of yarding disturbance could be reduced if settings are carefully designed. More intensive planning and consultation between resource managers can reduce the number of logging-associated slope failures. On marginally-stable slopes, the roads must be recognized as an integral part of the logging system. (Author's abstract)

Schroeder, W.L. and G.W. Brown. 1984. Debris torrents, precipitation and roads in two coastal oregon watersheds. pp. 117-122. In Proceedings of Symposium on Effects of Forest Land Use on Erosion and Slope Stability. May 7-11, 1984. Honolulu, Hawaii.

After the December 5, 1981, storm, a 5- to 7-yr event, at least 221 new landslides were observed on the Palouse and Larson Creek water-sheds in the central Oregon Coast Range. Engineering analysis indicates that such a storm provides sufficient water to induce landslides on cohesionless coastal soils, especially in uncompacted sidecast fills, which produce the largest slides. Fill failures are more likely to result from loss of soil strength due to increasing degree of saturation than from internal seepage. However, seepage from uncompacted fills may remove the toe and, by backward erosion, create a vertical face of sufficient height to initiate a slump. Numerous slope failures in both clearcuts and adjacent standing timber suggested that water, not deteriorating root strength, was the major factor initiating the observed landslides. (Author's abstract)

Sidle, Roy C. 1980. Slope stability on forest land. USDA Forest Service Ext. Publ. PNW-209. Pac. Northwest Forest & Range Experiment Station, Portland, Oregon.
23 p.

Sedimentation of streams resulting from mass soil movement is the most important problem of non-point pollution in the Pacific Northwest, according to state and federal regulatory agencies. Sediment in streams contributes to the deterioration of fisheries habitat and affects downstream water quality. Large mass movements that extend downslope directly into streams can scour channels and alter aquatic ecosystems for decades.

In order to minimize the impacts of forest practices on slope stability, forest and other resource managers must understand the characteristics and causes of various slope failures. (Author's abstract)

Sidle, Roy C. 1980. Impacts of forest practices on surface erosion. USDA Forest Service Ext. Publ. PNW-195. Pacific Northwest Forest & Range Experiment Station, Portland, Ore. 15 p.

Surface erosion can be initiated by forest practices such as timber harvest, road construction, and site preparation. A variety of management and control measures can help reduce this erosion. Surface erosion is generated by soil and operational conditions that are conducive to or cause disturbance and compaction. By using good operational and management techniques to minimize the extent to which disturbance and compaction occur, we can control the amount of surface erosion from managed forest

lands, insure high standards of water quality, and protect the forest land base for future timber production. (Author's abstract)

Sidle, R.C., A.J. Pearce and C.L. O'Loughlin. 1985. Hillslope stability and land use. Water Resources Monograph II. American Geophysical Union. Wash. D.C. 140 p.

The influence of natural and land management factors on slope stability is addressed extensively in this monograph. Comprehensive discussion of the major types of soil mass movement, slope stability analysis and the prediction, avoidance and control of soil mass movement is also presented.

Swanson, F.J., L.E. Benda, S.H. Duncan, G.E. Grant, W.F. Megahan, L. M. Reid and R.R. Ziemer. 1987. Mass failures and other processes of sediment production in Pacific Northwest Forest landscapes. pp. 9-38. In Proceedings of Symposium on Streamside Management: Forestry and Fishery Interactions. Feb. 12-14, 1986. Seattle, Washington.

Accelerated sediment production by mass failures and other erosion processes is an important link between management of forest resources and fish resources. Dominant processes and the rates of sediment production vary greatly throughout the Pacific Northwest in response to geologic and climatic factors. The complex sediment routing systems characteristic of the area involve numerous processes that move soil down hillslopes and sediment through channels. Sediment routing models and sediment budgets offer conceptual and quantitative descriptions of movement and storage of soil and sediment in drainage basins. Temporal and spatial patterns of sediment production and routing through basins have many direct and indirect effects on fish.

In addition to their role as dominant mechanisms of sediment production in many parts of the region, mass failures also affect the geometry and disturbance regimes of channels and streamside areas. Earth flows locally control the vegetation structure and composition of riparian zones through influences on valley floor width, gradient of side slopes and channels, and frequency of streamside debris slides. Debris flows can have long-term effects on channels and riparian zones in the context of an entire drainage basin, because effects vary with location in a basin.

Forestry practices can increase production of sediment. Results of experimental manipulations of vegetation on small drainage basins and studies of individual erosion processes indicate that debris slides and road surfaces are commonly dominant sources of accelerated sediment production. Some techniques are available for locating sites susceptible to accelerated erosion, for predicting change in sediment production, for evaluating the biological consequences of accelerated erosion, and for designing mitigation measures, but clearly more work is needed in each of these areas. (Author's abstract)

Swanson, F.J. and C.T. Dyrness. 1975. Impact of clear-cutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. Geology 3(7): 393-396.

The H.J. Andrews Experimental Forest can be divided into two zones of approximately equal area, each with strikingly different susceptibilities to erosion by rapid soil movements. A stable zone occurs at elevations above 900 to 1,000 m in terrain underlain by lava-flow bed rock. Since logging and road cutting began in 1950, only two small road-related slides have taken place in the stable zone. In contract, the unstable zone, located at elevations below 1,000 m and underlain by altered volcaniclastic rock, has been the site of 139 slides during the same period.

Slide erosion from clear-cut areas in the unstable zone has totaled 6,030 m^3/km^2, or 2.8 times the level of activity in forested areas of the unstable zone. Along road rights-of-way, slide erosion has been 30 times greater than on forested sites in the unstable zone; however, only about 8 percent of a typical area of deforested land in the unstable zone is in road right-of-way. At comparable levels of development (8 percent roads, 92 percent clear-cut), road right-of-way and clear-cut areas contribute about equally to the total impact of management activity on erosion by landslides in the unstable zone. The combined management impacts in the unstable zone (assuming 8 percent road right-of-way and 92 percent clear-cut) appear to have increased slide activity on road and clear-cut sites by about 5 times relative to forested areas over a period of about 20 yr. (Author's abstract)

Swanston, D.N. 1971. Principal mass movement processes influenced by logging road building, and fire. pp. 29-39. In Proceedings of Symposium on Forest Land Uses and Stream Environment. Oregon State Univ., Corvallis. August 1971.

Dominant natural soil mass movement processes active on watersheds of the western United States include: 1) debris avalanches, debris flows and debris torrents; 2) slumps and earth flows; 3) deep-seated soil creep; and 4) dry creep and sliding. A dominant characteristic of each is steep slope occurrence, frequently in excess of the angle of stability of the soil. All but dry creep and sliding occur under high soil moisture conditions and usually develop or are accelerated during periods of abnormally high rainfall. Further, all are encouraged or accelerated by destruction of natural mechanical support on the slopes. Logging, road building, and fire play an important part in initiation and acceleration of these soil mass movements. Road building stands out at the present time as the most damaging activity, with soil failures resulting largely from slope loading, back-slope cutting, and inadequate slope drainage. Logging and fire affect stability primarily through destruction of natural mechanical support for the soils, removal of surface cover, and obstruction of main drainage channels by debris. (Author's abstract)

Swanston, D.N. 1974. Slope stability problems associated with timber harvesting in mountainous regions of the western United States. USDA Forest Service General Technical Report PNW-21. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon. 14 p.

Natural soil-mass-movements on forested slopes in the Western United States can be divided into two major groups of closely related landslide types. These include, in order of decreasing importance and regional frequency of occurrence: (1) debris slides, debris avalanches, debris flows, and debris torrents;

and (2) creep, slumps, and earth flows. Each type requires the presence of steep slopes, frequently in excess of the angle of soil stability. All characteristically occur under high soil moisture conditions and usually develop or are accelerated during periods of abnormally high rainfall. Further, all are encouraged or accelerated by destruction of the natural mechanical support on the slopes.

As forest operations shift to steeper slopes, they play an increasing role in initiation and acceleration of soil mass movements. The logging operation itself is a major contributor through: (1) destruction of roots, the natural mechanical support of slope soils, (2) disruption of surface vegetation cover which alters soil water distribution, and (3) obstruction of main drainage channels by logging debris. Road building stands out at the present time as the most damaging operation with soil failures resulting largely from slope loading (from road fill and sidecasting), oversteepened bank cuts, and inadequate provision for slope and road drainage.

At the present time attempts at prevention and control are limited to identification and avoidance of highly unstable areas and development and implementation of timber harvesting techniques least damaging to natural slope stability. (Author's abstract)

Swanston, D. N. 1981. Watershed classification based on soil stability criteria. pp. 43-58. In Proceedings of Symposium on Interior West Watershed Management. Apr. 8-10, 1980. Spokane, Wash.

Judging the natural stability of a watershed and assessing soil mass movement hazards related to harvest activities is possible by combining subjective evaluation of factors controlling stability of an area and a limited strength-stress analysis based on available or easily generated field data.

The resulting analysis indexes the watershed in terms of relative hazard, identifies problem areas, defines failure mechanisms, and pin-points factors which may be amenable to specific control or correction procedures. (Author's abstract)

Thomas, Byron R. 1985. Uses of soils, vegetation and geomorphic information for road location and timber management in the Oregon Coast Ranges. pp. 68-77. InProceedings of a Workshop on Slope Stability: Problems and Solutions in Forest Management. Feb 6-8, 1984. Seattle, Washington.

Five major factors affecting slope stability are soil shear strength, soil depth, slope gradient, soil water, and root strength.

Soil shear strength is best determined by engineering tests conducted in the laboratory; however, it may be estimated in the field by using soil survey information in conjunction with conversion charts or by back calculation. Soil depth and slope gradient are determined directly by field measurements or interpretation. Soil water depth may be measured, modeled, or inferred from soil properties and geomorphic location. Root strength is inferred from research data correlating root decay over time since trees were felled.

At a qualitative level, some very effective assessments of occurrence or importance of these factors can be made by careful field observation and the use of aerial photos. Vegetative indicators provide many clues to soil wetness and incipient failures. These include occurrence of hydrophytic species and tipped or "crazy" trees. Bedrock topography that concentrates ground water may be readily identified in the field or with stereo pairs of photos. Geologic features such as fault zones or formations with known zones of weaknesses provide important information about stability to field personnel. (Author's abstract)

Vevinski, Carla L. 1982. Best Management practices for road activities. Volumes I and II. Idaho Dept. Health and Welfare. Division of Environment. Boise, Idaho.

This handbook consists of a discussion of road building and erosion and sedimentation and recommended practices to reduce these impacts. Volume I talks about the relationship between road project activities and water quality in Idaho. A BMP summary chart identifies recommended practices and presents them in four categories: soil stabilization, runoff collection and conveyance, runoff dispersion and dissipation and sediment collection. Volume II explains each practice in greater detail. Individual practices definition, purpose, applicability, planning criteria, methods, materials, maintenance and effectiveness are discussed.

Zaruba, Q. and V. Mencl. 1969. Landslides and their control. Elsevier, N.Y. 205 p.

The factors causing mass movements, mechanics of slope failures, geological definitions of the main landslide types, methods of landslide investigation, prevention of slope failures including a chapter on landslides and road construction, and corrective measures to stabilize slides are examined in this book. Each subject is discussed in depth and from several perspectives.

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